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TREND REPORT
SOCIAL NETWORK ANALYSIS

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Abstract This paper reports on the development of social network analysis, tracing its origins in classical sociology and its more recent formulation in social scientific and mathematical work. It is argued that the concept of social network provides a powerful model for social structure, and that a number of important formal methods of social network analysis can be discerned. Social network analysis has been used in studies of kinship structure, social mobility, science citations, contacts among members of deviant groups, corporate power, international trade exploitation, class structure, and many other areas. A review of the formal models proposed in graph theory, multidimensional scaling, and algebraic topology is followed by extended illustrations of social network analysis in the study of community structure and interlocking directorships.

The phrase 'social network', with its connotations of textiles, webs, and grids, conjures up a strange but surprisingly powerful image of social reality. Individuals are, as it were, tied to one another by invisible bonds which are knitted together into a criss-cross mesh of connections, much as a fishing net or a length of cloth is made from intertwined fabrics. The phrase has become the hallmark of a distinctive style of sociological work – social network analysis – which has developed greatly in the last twenty years as a fruitful approach to the analysis of social structure. Because of its recent growth and its often technical character, appealing particularly to those of a mathematical cast of mind, it is widely thought of as a recent innovation and as simply one of the large number of specialised technical methods used by sociologists. This view of social network analysis, while containing a degree of truth, is seriously misleading as an account of its origins and significance. While technical and highly mathematical applications of social network analysis have increased markedly in the last twenty years, the roots of the basic perspective are as old as sociology itself. This perspective, centred on the image of the intertwining of social relations, offers not so much a specialised method as a formulation of the fundamental concepts of the sociological enterprise. The aim of this report is to document this claim and to explore some of its more important implications.

The development of social network analysis

Sociology, from its earliest days, has been concerned with the ways in which the social relations between people constitute a distinct reality *sui generis*. This realm of social structure was seen as produced through the intersection of chains of action and their unintended consequences. While classical sociologists may have disagreed among themselves on the question of whether such structures were reducible, in principle, to the constituent social actions of the people who produced them, there was a general agreement that social structures had distinct and important properties

which provided the basic subject matter of the discipline of sociology. It was, perhaps, in classical German sociology that this viewpoint was most explicitly allied with the metaphor of a 'network' of social relations, the social world being depicted as an intertwined mesh of connections through which individuals were bound together. The very language used is redolent of the production of fabrics and textiles, and the works of Toennies, Weber and, above all, Simmel abound with concepts embodying such language: chains of action 'interweave' and 'interlock' to form a tightly 'knit' social 'fabric'. The purpose of metaphor in science is to make the unfamiliar understandable by describing it as if it were analogous to a familiar object or process. The metaphor of 'social network' served to make the complex and unfamiliar patterns of the social world comprehensible by relating them to well-understood everyday concepts drawn from the production and handling of textiles.

The first true formulations of social network analysis, in which the metaphor was taken seriously as the basis for developing a battery of sociological concepts, took place in social psychology. In the 1930s Moreno began to develop what he called 'sociometry' as a way of conceptualizing the structures of small groups produced through friendship patterns and informal interaction (Moreno 1953). The 'stars' of social interaction – those who received a large number of friendship choices from others – were dramatically depicted in Moreno's 'sociograms' as the hubs of radiating patterns of lines, each line representing a friendship choice directed from one person to another. Through the use of such diagrams Moreno was able to develop the metaphor of the network into a fruitful, but still rudimentary, sociological concept. Bavelas (1948) and Festinger (1949) considerably enlarged on this work and laid the foundations for the study of 'group dynamics', which comprised the backbone of American social psychology in the 1950s and 1960s and which was codified in the well-known textbook by Cartwright and Zander (1954).

Independently of these developments certain British sociologists and social anthropologists also began to take the metaphor seriously during the 1950s. John Barnes, reflecting on the activities of Norwegian fishermen, began to realise the close analogy between the nets used by the fishermen and the structure of the village community in which they lived (Barnes 1954). This insight was fruitfully developed in subsequent research, initially by those studying African tribal societies and urban communities and by those studying family and community structure in Britain. Fortes (1949) wrote of the web of kinship and Nadel (1962) suggested a formalisation of the network metaphor, but the most powerful anthropological developments were associated with the work on African societies carried out at the University of Manchester and brought together in *Social Networks in Urban Situations* (Mitchell 1969). Sociologists and anthropologists interested in family and community in Britain took their lead from Bott's employment of Barnes' ideas in her study of conjugal role relationships (Bott 1957), and allied this with the more descriptive tradition of community studies initiated by Young and Willmott (1957). In these works, synthesised in Frankenberg (1966), the network metaphor was used to describe variations in the quality of kinship relations and their connection with wider communal patterns of neighbouring and working. The various strands in this British tradition of work, sociological and anthropological, were explored and elaborated in a collection compiled by Banton (1966).

Bott's study was, and remains, influential among researchers into family and kinship, and it serves as an example of the fruitful way in which the intuitive idea of

a social network was applied by earlier writers. She was concerned with social relations in urban families, and especially with patterns of conjugal roles. On the basis of interviews with twenty families she concluded that variations in conjugal role relationships were 'related to the form of the family's informal social network, that is, to the patterns of social relationships with and among friends, neighbours, and relatives' (Bott 1957:3). Bott rejected simple correlations between role structure, on the one hand, and class and neighbourhood, on the other, arguing that these were mediated through the informal networks of the families. Segregated conjugal relationships, she argued, occurred where both partners had 'close-knit' networks. Under such circumstances husband and wife were each embedded in dense, but distinct, networks of friendship and kinship. As a result, there was a tendency for them to continue to be drawn into separate activities outside their elementary family. Where social networks of the marital partners were 'loose-knit', however, there was a greater mutual reliance of husband and wife and so a tendency for them to pursue activities jointly. Bott's general conclusion was that 'the degree of segregation in the role-relationships of husband and wife varies directly with the connectedness of the family's social network' (1957:60, emphasis removed).

The key element in both the American and the British research was a concern for the structrual properties of networks of social relations, and the introduction of concepts to describe these properties. In the work of social psychologists, particular attention was given to the 'centrality' of different actors in the patterns of communication of small groups, while sociologists and anthropologists were more interested in what they variously described as the 'density' or 'connectedness' of large social networks. Though evolving novel concepts, these writers did not advocate network analysis as a specialised technique within sociology. Social network analysis was not simply to supplement the existing battery of statistical and other mathematical methods. Rather, they sought to emphasize that there was something fundamentally wrong with a sociology which did not recognise and take seriously the patterns created by social relations. Social network analysis, therefore, offered a new way of looking at old problems, a new perspective in which the metaphors used by sociologists since the founding of the discipline could be forged into powerful theoretical concepts.

Paradoxically, however, it was an upsurge of interest in the mathematics of network analysis which was responsible for a major expansion in social network analysis in the 1960s and 1970s. In geography, economics, and linguistics, as well as in sociology and social anthropology, more and more social scientists became convinced of the power inherent in social network analysis and sought to extend the scope of its application. Especially important were the large number of new recruits to the expanding American graduate schools, whose expertise in what rapidly became a rather esoteric technique was of considerable value in promoting their professional careers. A key role in the development of social network analysis, and in helping to translate the mathematical formulations into meaningful research programmes, was played by the group of graduates trained in Harvard's Department of Sociology by Harrison White, who combined a concern for rigorous mathematics with a respect for classical theory. This group of sociologists, including Berkowitz, Schwartz, Levine and Wellman, furthered social network analysis as they moved from Harvard to their first professional appointments in universities throughout North America, and by the middle of the 1970s social network analysis

had become established as a research specialism with an international base (Mullins 1973), though in Britain, paradoxically, its rate of growth has been far slower (Mitchell 1985).

This group of researchers – a network of networkers – was not, however, an enclosed specialism sharply separated from others, though it had established its own journal (*Social Networks*) and newsletter (*Connections*).[1] Social network analysts were drawn from a diverse range of substantive specialisms, ranging from their traditional concerns of family and community structure and group dynamics to such areas as elites and power, interlocking directorships, labour market studies of careers and recruitment, social stratification, science citation studies, health and welfare provision, crime and deviance, and the global economy. Network analysts were, in fact, to be found in almost all areas of sociological specialisation. What united them was a commitment to the underlying frame of reference of social network analysis, which illuminated the common structural concerns of researchers in these diverse areas. The leading writers in North American social network analysis have forcefully reiterated the claim that the network concept is central to sociology, and is the most fruitful way of developing that structural analysis which the classical sociologists emphasised as the distinguishing feature of the discipline as a whole (Wellman 1981; Berkowitz 1982; Berkowitz and Wellman 1986). In making such claims they are reasserting the earlier views of Barnes and Mitchell, who have both sought to review the implications of these developments (Barnes 1972; Mitchell 1974. See also Blau 1982).

Models for social networks

The central question in the development of social network analysis has been that of how the metaphor of a social network is to be taken seriously. Social network analysis, it has been argued, depicts agents – individual or collective – as embedded in webs of connections, and the task of the sociologist is to describe and explain the patterns exhibited in these connections. The image of a fishing net, with its knots and tangles and its variations of fine or open mesh, accords with our everyday imagery of social relations, but how is this to be converted into a useful sociological concept? At its simplest, the idea of a network involves a set of points connected by lines, and it was this idea which led the earliest proponents of social network analysis to turn to the mathematical theory of graphs in the hope of discovering a formal model for the representation of network structure. The formal concepts of graph theory have been raided by sociologists who have seen this as a straightforward way of evolving novel sociological concepts. This has, however, sometimes led to the mathematical tail wagging the sociological dog: because a formal concept existed in graph theory (for example, the 'diameter' of a graph), and because this could be converted into a measurable feature of social relations, it has sometimes been assumed that is must, therefore, reflect a significant aspect of social life. Sociologists cannot, however, simply turn to graph theory – or any other branch of mathematics – and mechanistically apply it to the study of social relations. It is always necessary to decide which measures are theoretically and empirically appropriate for the subject under investigation. Mathematics can be an extremely powerful aid to social network analysis, but it can never obviate the need

to make theoretical and empirical decisions about the significant sociological properties of social networks. It is for this reason that graph theory has not gone unchallenged, and alternative models for social networks have been proposed.

With this proviso in mind, it is possible to review the basic ideas of graph theory, which, despite the forbidding name and the many highly technical formulations which it contains, are remarkably simple and clear. The earliest codifications of graph theory aimed specifically at sociologists were those of Coleman (1964) and Harary et al. (1965), while in Britain Doreian (1970) attempted a similar task. The mathematical concept of a graph involves the idea of points (or 'nodes') connected by lines (sometimes termed 'edges' or 'arcs'), and graph theory comprises a set of procedures for analysing the presence, direction and strength of the lines which connect these points.

Figure 1 depicts a simple graph, which will illustrate some basic graph-theoretical ideas. Seven points, labelled A to G, are connected by six lines, and it is initially important to emphasise that the arrangement of the points on the page is purely arbitrary and can be varied at the whim of the researcher, who will naturally seek the clearest visual arrangement, and all that matters is the pattern of connections. Thus, points B and F appear closer on the page to one another than do points B and E, but this is purely an artefact of the way in which the diagram was drawn. Graph theory takes no account of our conventional representation of physical 'distance' – a feature to which it will be necessary to return later – and measures the distance

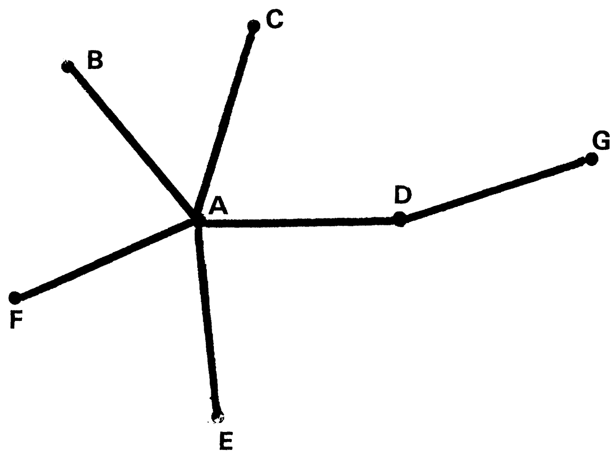

Figure 1.

between points solely in terms of the number of lines which it is necessary to traverse in order to get from one point to another. The graph distance from B to F, therefore, is two lines (BA and AF), which is exactly the same as the distance from B to E (through lines BA and AE). The distance between any two points in a graph, then, is equal to the number of lines in the path between them: the distance from B to G, for example, is three lines.[2]

This concentration on patterns of connection, rather than spatial distance, shows the roots of graph theory in 'topology', the branch of mathematics concerned only with the shape or form of structures (Barnes 1969:216–7). It is not surprising, therefore, that sociologists employing topological ideas have remarked on its compatibility with Simmel's 'formal' sociology (Berkowitz 1982:20). As in Simmel's stress on the dyad and the triad as fundamental forms of sociation (Simmel 1908), graph theorists explore the ways in which complex graphs are built from simpler structural elements. A simple dyad comprises two points connected by a line, and such points are said to be 'adjacent' to one another. The graph in Figure 1 consists of six such dyads chained together (AB, AC, AD, AE, AF, and DG), but illustrates clearly that the structure of the graph is not reducible to the properties of the separate dyads. It is obvious visually that point A occupies some kind of central position in the graph, and its centrality derives from its involvement in five of the six dyads. Removing A from the graph results in a marked change in its structure, while removing B has far less impact. Graph theory formalizes this notion of centrality through a measure of 'adjacency'. The adjacency of a point is simply the number of other points to which it is adjacent, and it is easy to calculate for Figure 1 that A has an adjacency of five. This compares with an adjacency of two for point D, and an adjacency of one for each of the other points. Thus, by calculating the adjacencies of all points in a graph it is possible to discover which are most central to it. It is perhaps important to emphasise again how graph theory departs in some respect from commonsense ideas. A central point in a graph is not like the centre of a circle: it is not to be thought of as somehow 'in the middle' of the graph. The adjacency of a point measures its centrality only among those points in its immediate vicinity, and a complex network may contain a large number of such central points. For this reason, graph theorists have developed a whole battery of other measures of centrality, aimed precisely at distinguishing those points which are locally central from those which occupy a global position of centrality in the network as a whole (Freeman 1978; Bonacich 1986).

The graph theoretical idea of centrality was important for the American social psychologists concerned with the sociometric 'stars', the centres of attraction, in small groups. The early British social network analysts, on the other hand, were far more concerned with the 'density' of the networks which they studied. In graph theory, density is the ratio of the actual number of lines in the graph to the number which would be present if all points were connected to all others. It is logically possible for seven points to be completely connected through 21 lines – each pair of points connected by a line.[3] The seven points in Figure 1 actually are connected by only six lines, and so this particular graph has a density of 6/21, or 0.29, indicating that slightly under one third of the possible lines are present.

As the measure of density can vary from zero to one, the graph in Figure 1 would seem to have a moderately low density. But this may be a misleading line of reasoning to follow when dealing with the graph of a social network. The number of

contacts which a person can sustain varies with the nature of the social relationship involved, and this imposes limits on the maximum density. While it is possible for the 500 people working in a particular organisation to be 'aware' of one another as members of the organisation, it is unlikely that they would all be able to 'love' one another. The maximum density for the relation of 'awareness', therefore, may be one, while the maximum density for the relation of 'loving' might be expected to be much lower. The assessment of the actual density discovered in a social network, therefore, must take account of the size of the network (how many people are involved) and the type of relation (the ability of people to sustain such contacts). The mathematical properties of the density measure must not blind the researcher to its substantive implications (Barnes 1979:416 – 8; Friedkin 1981). A graph density of 0.29 may, under certain circumstances, indicate a very high level of cohesion in the social network which it represents.

Density measures have been used to identify the existence of 'clusters' in a graph, though this is not the only way in which clusters have been defined (Everitt 1974). A cluster can be seen as a relatively densely-connected clump of points within a larger, and less dense, graph. If point G in Figure 1 were to have a similar adjacency to point A through being connected to four additional points (H, I, J, and K), then the overall graph could be interpreted as comprising two clusters – (A,B,C,D,E,F, and G,D,H,I,J,K) – connected through their common member D. Such a graph, shown in Figure 2, would contain ten lines and eleven points, giving it an overall density of

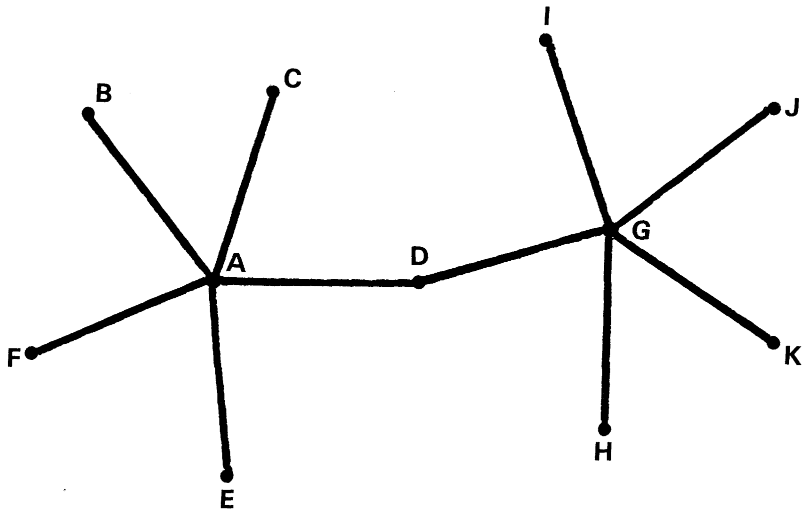

Figure 2.

0.18; the two clusters would stand out because they each have a density higher than that of the whole graph. However, the identification of clusters always depends upon the decision of a researcher as to what is to be treated as an acceptable level of density to define clusters in this particular network.

Closely allied to the concept of cluster is that of 'clique', though this too has been defined in numerous ways. Where a cluster is most usefully seen as an area of a graph – a so-called sub-graph – with relatively high density, a clique is an area in which all points are connected to one another by paths of a specified maximum distance. If the maximum distance acceptable to the researcher is set at one line, then a sub-graph would have to be completely connected (each point directly connected to all others) in order to qualify as a clique. A less restrictive criterion would be to allow a maximum distance of two, in which case a clique would comprise a number of points which were either directly connected or connected through a common neighbour. On this criterion points A to F in Figure 1 would constitute a clique, as no point is further than two steps from any other. In that graph, therefore, only point G would lie outside the clique, as it is a distance of three lines from all points except A and D. Were the maximum path length for clique identification to be set at three lines, then the whole graph in Figure 1 would comprise a single clique. The decision as to what is and what is not acceptable as a criterion for clique identification rests, once more, with the researcher.

This rapid review has ignored some of the diversity in terminology and conceptualisation which exists, since its aim has been to bring out the important ideas shared by graph theorists. Further concepts are introduced and more complex issues raised in a number of the texts and reviews already mentioned (and see also Hage and Harary 1983). The important conclusion to draw is that graph theory does, indeed, offer a powerful way of representing some of the principal features of social networks, but that it cannot be applied in a mechanistic way. As has been emphasised above, the sociologist must always remain in command of the mathematics, rather than the mathematics determining its own areas of application.

Some applications

Research using social network analysis has been undertaken in many different areas. Such obvious applications as those in kinship and community studies have been followed by investigations of social mobility, class structure, perceptions of class, corporate power, international trade exchanges, contacts within deviant groups, welfare support, science citations, migration patterns and reactions to disasters. It has even been rumoured that social network analysis has been used by security agencies in tracing terrorist networks. Most recently, innovative studies have begun to use network concepts in tracing the spread of AIDS through sexual contacts and in devising strategies for limiting further infection (Klovdahl 1985).

In order to illustrate the uses of social network analysis in sociology, I have chosen examples from two major areas of research: community studies and interorganisational relations. The research chosen for discussion in each of these areas is representative of the most systematic social network analysis carried out and, *inter alia*, examplifies two distinct, but interdependent, concerns in research on social networks. Reseachers may be concerned with either the 'local' or the 'global'

properties of networks. In the first case interest is centred on personal, ego-centric networks, the researcher examining the specific connections sustained by the individuals in the study in isolation from the structure of the network as a whole. An interest in the global features of networks involves a corresponding isolation from the local details of individual connections. While most researchers combine both interests in varying degrees, it will often be the case that one or the other predominates. In the work to be discussed here, community research exemplifies a concern for personal networks[4] and interorganisational research a concern for the global properties of networks.

An authoritative review of the field of community studies has described Barnes' idea of social network as the 'first *major* advance in the language of sociology since role' (Frankenberg 1966:242), and so it is hardly surprising that community studies have continued to explore the implications of this concept. Much early work on urbanisation saw it as involving a 'loss' of community and the creation of the impersonal metropolitan areas of mass society. Empirical work on urban areas, however, found that the thesis of the loss of community failed to recognise the true nature of urban social bonds. In an attempt to provide an alternative theoretical framework, Frankenberg used the concept of social network to systematise what he termed a 'morphological continuum': 'truly rural' societies are characterised by *close-knit* social networks in which everybody knows and interacts with everyone else, while in urban situations social networks are loose-knit and allow greater anonymity and independence of action (Frankenberg 1966:286–92). The reconsideration of 'community' was taken a step further by Stacey (1969), who introduced the important idea of the 'local social system'. This is seen as an arena of social interaction which does not totally enclose the actions of those who live within it and is not necessarily centred around intimate, harmonious, and affective social relationships. Social networks may transcend such localities, and a commentary on this reconceptualisation concludes that 'Traditional notions of community may be subsumed under the label of "locality bound, close-knit network"' (Bell and Newby 1971:53).

An important study of urban social networks in a Canadian city shows how the systematic use of social network concepts can enable researchers to test and extend this understanding of community. Its hypothesis was that the transformation of most neighbourhood relations into 'low intensity "nodding" acquaintanceships, with some visiting and non-onerous mutual aid' was associated with the existence of widely dispersed friendship and kinship ties which were intense and intimate in character (Craven and Wellman 1973). A sample of 845 adult residents of East York, Toronto, were asked, among other things, to name the 6 people, outside their own home, to whom they felt the closest, and further questions were asked about the quality and strength of these relationships and about the connections among the named people. The aim was to construct the personal social network of each person – the 'ego-centric' network of immediate contacts and their mutual links – and it was found that these networks did indeed tend to spread beyond East York and the Toronto metropolitan area: a quarter of all close bonds, predominantly involving kin, were with people resident outside Toronto. Not all household members were of equal importance in maintaining these close social bonds. A follow-up study explored the relationship between communal bonds and work participation and discovered, for example, that women engaged in both domestic

and paid work were of particular importance in maintaining the personal networks of their households, while men tended to be more passive network members (Wellman 1985).

The utility of social network analysis in this study is particularly evident from the use made of the graph – theoretic concept of density to study the question of how close-knit people's networks were. Wellman (1979) calculated the mean density of personal networks in East York as 0.33, indicating that an average of one third of the possible relations among the six intimates of individuals actually existed.[5] This reflected the division of the majority of personal networks into kin and non-kin segments, with little connection between the two: people tended to keep their close friends and close kin in two separate compartments. It was further discovered that there was little overlap among the personal networks of different individuals, indicating that it was not the case the 'everyone knows everyone else'. The total social network of East Yorkers, insofar as it could be inferred from personal networks, was indeed loose-knit and widely dispersed; it was neither close-knit nor locality bound. These issues in urban frienship and neighbouring have been further explored in such important studies as Wallman (1984), Bulmer (1986) and Willmott (1986).

Interorganisational research focused on interlocking directorships was stimulated especially by discussions of the concentration of economic power by Marxists, with their concept of 'finance capital', and by those American liberals concerned with the threat to individualism posed by the 'Money Trust' of big bankers (Di Donato et al. 1986; Scott 1985: Chapter 4). Although commentators and researchers from the early years of the century onwards spoke of the 'webs' and 'chains' of interlocking directorships which 'entwined' the major business enterprises, the concept of network did not become a systematic research tool in this area until the early 1970s, when researchers in the United States and, soon after, in Canada, The Netherlands, Britain and elsewhere began to apply the techniques of network analysis. The first published outcome of this growth of interest was Levine's (1972) use of a form of MDS to display the structure of bank-industry interlocks in the United States.[6] Most subsequent writers in this area, however, have employed graph theory.

One early paper disarmingly illustrated the way in which the choice of a mathematical model may pre-empt the intellectual judgement of the researcher. Graph theory was employed to report on corporate interlocks, but a whole battery of measures was prefaced by the proviso that the substantive meaning of the measures had not yet been discovered. The authors assumed that the possibility of measuring the formal properties of a network necessarily implied that the measurements had a substantive meaning. As a result, a number of undigested and uninterpreted findings were reported.[7] These and subsequent researchers have, however, come to realise that mathematical measurements make sense only when there are good theoretical or empirical reasons for making them.

An important example of this work is provided by the Stony Brook group of researchers in an extremely influential unpublished paper (Bearden et al. 1975). These researchers studied interlocking directorships in large American enterprises during the period 1962 – 73, their interest being in the structure of the network as a whole. They found the existence of an extensive and relatively cohesive national network, but discovered a different pattern when they isolated the interlocks carried by those who were executives in the enterprises. These interlocks – termed 'primary

interlocks' – were intense links which created close-knit, bank-centred groups with a distinct regional character.

These 'interest groups' were identifiable as cliques within the network of primary lines, and had some similarities with the financial interest groups depicted in Marxist theory: they were structured around banks, and the interlocking directorships were associated with indebtedness, intercorporate shareholdings, and economic interdependence. The Marxist interpretation was rejected, however, because the cliques did not exist as sharply distinguished groups. The regional structure of 'strong ties' was embedded in a more extensive and loose-knit national network, in which the executive and non-executive directors of the New York banks played a key role. Their interpretation of this structure owed much to Granovetter's (1973) seminal analysis of the important role played by relatively 'weak' ties in loose-knit networks.

The main concept and discovery to emerge from this paper was the idea of 'bank centrality', and this has been the foundation of much recent work aimed at building on the Stony Brook research. (See Mizruchi 1982; Stokman et al. 1985; Scott and Griff 1984). Particularly important has been the work of Mintz and Schwartz (1985), who have claimed that 'bank centrality' in networks of interlocking directorships is indicative of the 'financial hegemony' of large financial institutions. This argument has been further explored by an examination of shareholding networks in Scott (1986), while Useem (1984) has suggested how studies of interorganisational relations might be linked with the concerns of class analysis.

Some unresolved problems

The two major difficulties with graph theory are that it ignores conventional notions of distance and spatial arrangement, and that it is limited to two-dimensional representations of multidimensional social networks. These are, in fact, interrelated. The sociograms produced by graph theorists seek to give a clear visual representation of the social network to which they refer, and the aim is to arrange the points on the page in such a way that there are a minimal number of cross-overs among the lines. Thus, points are arranged and rearranged in terms of this aesthetic goal. Where the researcher aims also to keep all lines of equal length, to represent the fact that they are regarded as representing equal 'distances', it can prove impossible to achieve this with graphs of any size or complexity. This difficulty however, has more than simply aesthetic implications, as it points to the limitations of two-dimensional representation.

A simple graph such as that of Figure 1 can easily be arranged in the dimensions of a flat page: the arbitrary arrangement of the points was specifically designed to ensure that all lines were of equal length (the graph theoretic requirement) and that no line crossed any other (the aesthetic requirement). If more lines or additional points had to be added it would be necessary to re-arrange the points to continue to meet these requirements. But the time would soon come when one or both would have to be abandoned: the reader is invited to consider the problem of drawing an extension of Figure 1 in which a new point H, is connected to points B, C, E, and F.[8] If the maintenance of lines of equal length is made the fundamental requirement,

then a small amount of cross-over among these lines can be handled by making the sociogram into a three-dimensional model. That is, the principles of perspective drawing could be employed to imply that the figure on the page is actually a representation of a three-dimensional structure. But even this artifice will not suffice for graphs with many cross-overs, as these indicate that the graph must be thought of as existing in four or more dimensions – and a perspective drawing cannot imply more than a third dimension.

Multidimensional scaling (MDS) has been proposed by a number of writers as a solution to these difficulties. MDS is a set of procedures (Davies and Coxon 1982; Coxon 1982) for converting data about the similarities or dissimilarities among objects into a non-arbitrary spatial arrangement, and is derived from the trigonometrical and projection techniques of map makers. If a cartographer has surveyed the distances between various towns, straightforward procedures are available for converting these data into a map in which the spatial arrangement of the towns corresponds to the surveyed distances and from which accurate bearings between towns can be calculated. Such 'metric' data[9] are rare in the social sciences, and MDS allows the researcher to use measures of similarity and difference – generically termed proximity measures – as proxies for distance. Measures of, for example, *per capita* income differentials among towns can be used in MDS to produce a configuration of the towns in which their positions represent not their physical position but their location in the space defined by the distribution of income. Towns with low incomes might be found clustered in one part of the configuration, while the more prosperous towns would lie in another part. MDS, therefore, provides a way of mapping sociological data into a form analogous to the maps of conventional geography and everyday life.

The relevance of MDS to social network analysis is that the social relations between agents can be thought of as bringing them 'closer' or 'further away' from one another in a spatial sense. The number and type of social relations, for example, can be converted into proximity measures. Instead of the arbitrary arrangment of points and lines which is produced in a graph-theoretic sociogram, MDS can use line distances in the graph to construct a meaningful configuration of points. Distance in such a configuration is represented directly by physical propinquity, and so the lines which connect the points, if these are included, need not be of equal length; lines indicate simply the patterns of connection, the 'routes' from one point to another (Levine 1984).

The cartographer uses distance data to produce a two-dimensional configuration; the distances between towns, for example, are represented in a space defined by the two dimensions 'north-south' and 'east-west' to yield a conventional flat page atlas map. This already involves some simplification of the data, which may more realistically be represented in a three-dimensional model which takes account also of altitude. This is central also to MDS, which, as its name implies, represents social data in as many dimensions as are necessary to produce the best possible fit between the raw proximity data and the final spatial configuration.[10] The results from MDS, therefore, will show the co-ordinates of each point on each of a number of dimensions. The purpose of producing a spatial arrangement, however, is that it is a model of the data which can be inspected visually in precisely the same way as a road map, and this requires the use of a limited number of dimensions. On a printed page only two dimensions can be used, and a maximum of three dimensions can be

implied through perspective drawing.[11] If more dimensions are required to produce a good fit, then the researcher must resort to some simplification: a three-dimensional solution, for example, can be represented as three separate two-dimensional diagrams (dimension one against two, two against three, and one against three), and a four-dimensional solution could be represented as six two-dimensional diagrams.

Once again, terrestrial cartography provides an analogy. The three-dimensional earth can be presented in a conventional north/south and east/west map, and in two sections in which altitude is combined first with the north/south dimension and second with the east/west dimension. Each of these three diagrams involves some distortion, as a third dimension is, in each case, 'collapsed' into the other two. The distortions introduced by this collapsing may be so great that interpretation of the configurations becomes extremely difficult, though the peculiarities of the terrestrial world are such that this is not an insuperable problem for map makers. The conventional atlas map involves far less distortion than the two sectional diagrams because the magnitudes involved in the measurement of altitude are so much less than those arising from the measurement of distance along the surface of the earth, and altitude can be adequately represented on the map by contour lines and spot heights.[12] This will not always be the case with the data employed in the social sciences and, when the number of dimensions is greater than three, the distortions involved in two-dimensional representation may be so great that interpretation of the spatial arrangements becomes extremely difficult.

Paradoxically, therefore, multidimensional scaling faces the same problem of visual representation as graph theory. Despite producing co-ordinates for *many* dimensions, MDS can display these only in *two* dimensions. One of the advantages of MDS over graph theory – its ability to produce a non-arbitrary configuration of points – proves to be only a partial solution to the problems of graph theory. The structural properties of multidimensional configurations must be grasped and conceptualised in more abstract terms. The concepts of graph theory (such as centrality and density) provide intuitively understandable visual images which can be generalised to four or more dimensions, even if they cannot actually be directly visualised at this level of abstraction. Attempting to 'collapse' such representations into two dimensions results in considerable distortion, and the visual image of the structure can be lost.

The fundamental problem in applying graph theory in the social sciences, however, would seem to be the rooting of its concepts in the image of people as 'points' from which more complex structures are built. When a social network is modelled by graph theory, it is conceptualised as a string lattice similar to Barnes' original metaphor of the fishing net. But applications of social network analysis have shown the limitations of this particular imagery. People are better conceptualised as being complex structures, as complex articulations of roles and relationships. From this point of view, the human agent is intrinsically multidimensional, and any formal model which is limited to the two-dimensional representation of social structures will be inadequate. For this reason, a number of social network analysts have begun to turn to a branch of mathematics, algebraic topology, which seems to offer a solution to this problem. More specifically, there has been a growth of interest in Atkin's development of algebraic topology, Q-analysis, which begins from just such a view of human agency (Atkin 1981. See also Atkin 1974; Abell 1969; Freeman 1980; Doreian 1980, 1981, 1982).

Atkin's basic assumption is that any object must be described not as a 'point' but as a geometrical figure called a 'simplex'. A simplex is defined by the number of dimensions which are required to specify the space in which it exists. Thus an object which is to be defined, for the purpose in hand, by two attributes must be represented in one dimension (as a line connecting the points which represent the attributes), and an object defined in terms of three attributes must be represented in two dimensions (as a triangle). These objects are described by their dimensionality as, respectively, a one-simplex and a two-simplex. This scheme of analysis can be generalised to multidimensional space to cope with the fact that human agents will invariably be defined for sociological purposes in terms of a large number of attributes: for example, by their relationships to each of the other members of their family, work orgainsation, or locality. Each person, therefore, is to be conceptualised not as a 'point' but as a solid piece of multidimensional goemetry which articulates with other such pieces to form complex social structures – termed 'simplicial complexes' – which exist in a multidimensional space of the kind generated by MDS.

Q-analysis has, as yet, produced only a very few alternatives to the leading graph theoretic concepts, though important work has begun to push this further (Johnson, 1983, 1982). It remains to be seen exactly how such intuitively plausible, but ultimately misleading, graph-theoretic concepts as density, for example, can be translated into the more adequate multidimensional concepts of Q-analysis (Earl and Johnson 1981).[13] The day when the insights of graph theory and MDS will be incorporated into the language of Q-analysis is still a long way off.

An alternative approach to modelling social structure, termed blockmodelling[14], has attempted to move in a different direction. Attention is given not so much to the connections of individual points as to the relations between *sets* of points. By contrast with the clique-detection procedures of graph theory, blockmodelling aims to partition points into a discrete number of sets on the basis of 'structural equivalence'. Points are regarded as being in a structurally equivalent position when they occupy a similar position in the overall structure: a position of dominance or subordination, for example. Graph theory has great difficulty in handling situations where the same points are related to one another in two or more distinct relationships – kinship and business transactions, for example – and resorts to the practice of simply aggregating the relations into a single network. This is a dubious procedure, and blockmodelling avoids the difficulty by searching for similarity of pattern in the various networks. Blockmodellers ask whether a 'dominant' block in one network also occupies a dominant position in another.

No one approach can yet claim a monopoly of attention, and it is likely that further advance will require a greater accommodation among the competing approaches. Graph theory, which has for so long led the way, has come increasingly to be challenged, and its dominance is no longer assured. Nevertheless, even its impoverished language has enabled sociologists to carry out some powerful pieces of social network analysis.

Conclusion

In this report I have tried to argue that social network analysis has a long history in sociology, but that it is only in the last thirty years that the metaphor of social

network has been used in a theoretically rigorous way. Of major importance in stimulating this work, and in encouraging the application of social network analysis to particular areas, has been an interest in formal, mathematical models of networks. The choice of an appropriate model, however, is not a straightforward, theoretically-neutral task, but depends upon the intellectual judgement of the researcher. If social network analysis is to continue its growth and to evolve into the 'structrual analysis' advocated by some of its proponents (Berkowitz 1982), this message must be taken seriously. If it is not, and those interested in social network analysis allow unproven mathematical models to determine the shape and presentation of their work, then social network analysis will fail to have the impact which is its due.[15]

Notes

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1. *Connections* is published three times each year, and is available to members of the *International Network for Social Network Analysis*. INSNA is organised by Barry Wellman, Centre for Urban and Community Studies, University of Toronto, 455 Spadina Avenue, Toronto, Canada, M5S 2G8.
2. Strictly speaking, distance is measured only by the length of the shortest path between two points. If points C and D in Figure 1 were directly connected by a line there would be two distinct paths connecting B and G, one of length three (BADG) and one of length four (BACDG). In more complex graphs there may be numerous alternative paths of varying length, and so distance is standardised to the shortest path.
3. The number of possible pairs is actually 42 (i.e. 7×6), but in an 'undirected graph' the line connection A to B, for example, is regarded as identical to the line connecting B to A and so the number of distinct pairs is 21.
4. It is perhaps worth pointing out that the study of 'personal' networks is not limited to research on individual persons. The distinguishing feature of this kind of study is that the networks studied are centred on the agents chosen for study, and these agents may be individual or corporate.
5. The six lines between 'ego' and his or her intimates existed by definition and were not included, as Wellman was interested in the links among the intimates themselves. As each of the six could be close to each of the remaining five there were 15 possible lines, of which an average of five actually existed. This level of density can be compared with that for the artificial data of Figure 1.
6. The other American pioneers were Bearden et al. (1975) and Sonquist (1975). In other countries there was the work of Whitley (1973); Helmers et al. (1975); Scott and Hughes (1975, 1976); and Stanworth and Giddens (1975).
7. The paper in question was a draft marked 'Not for citation or quotation', and later reports by the authors have been among the most sophisticated in the area.
8. Scott and Hughes (1980) is a study of interlocking directorships in which a number of arbitrary and *ad hoc* solutions are employed to try and resolve this difficulty in drawing sociograms. Even when partial networks, rather than the whole network, were considered, it was not always possible to avoid relaxing one or both of the requirements. It was impossible to produce graph theoretic representations of the whole network of interlocking directorships.

9. Metric measures observe specific mathematical requirements and operate with actual numerical values. Non-metric measures take account only of such things as differences and rank orderings.
10. The goodness of fit between the original data and the final configuration is generally measured by some co-efficient of 'stress' and the aim of the analyst is to choose that solution which minimises stress.
11. As far as the cross-cutting of lines is concerned, therefore, MDS faces the same difficulty as graph theory. In so far as the lines are no longer required to indicate distance, however, the intersection of lines can become a useful indicator of the density of connection. Levine (1984) pursues this idea and uses colour variations to bring out the relative importance of different kinds of connection.
12. I ignore here the further distortions involved because of the curvature of the earth's surface. This is, of course, a key problem in cartography. See some discussion in Levine (1972) and Scott (1975).
13. By using the word 'translation' here, I do not mean to imply that there is a direct one-to-one relationship between the two languages. Any translation is also a transformation.
14. The most important versions of this are the various blocking procedures of White and Burt, which combine elements of graph theory with algebraic topology. See White et al. 1976; Boorman and White 1976; Burt 1982).
15. A number of computer packages are now available for use in social network analysis, and a detailed knowledge of their underlying mathematics is not necessary for their use. GRADAP implements graph theory, UCINET is a general purpose package for the IBM PC, and STRUCTURE, also for the IBM, uses a variant of MDS, and the MDS (X) package offers a range of multidimensional scaling procedures. A number of useful programs are described in Mitchell (1985). All three packages handle complex data, GRADAP accepting files in SPSS format, and STRUCTURE allows output to be passed to other packages.

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